Determination of the cross sections of (n,2n), (n,γ) nuclear reactions on germanium isotopes at the energy of neutrons 13.96 MeV

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Abstract

The cross sections of ^{70}Ge(n,2n)^{69}Ge, ^{72}Ge(n,2n)^{71}Ge, ^{76}Ge(n,γ)$^{77(g+0.21m)}$Ge, ^{76}Ge(n,2n)^{75}Ge nuclear reactions were measured at the energy of neutrons (13.96±0.06) MeV by activation method with γ-ray and X-ray spectra studies.

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I. INTRODUCTION

Germanium is the the material for the detectors which can be used at the measurements of γ-ray spectra [1, 2] or charged particles energy [2] under fast neutrons background existence. To calculate the contribution of these neutrons to measured pulse-height spectra one must have a set of reliable experimental data. Experimental results on nuclear reaction cross sections in this energy region also are useful for testing nuclear reaction models. From this point of view there is no information on experimental measurements of ^{72}Ge(n,2n)^{71}Ge and ^{76}Ge(n,γ) nuclear reaction cross sections at the considered neutron energy range [3]. But these nuclear constants could be measured by means of activation technique.

II. METHOD OF THE EXPERIMENT

The samples of polycrystal germanium, of metallic zirconium and niobium were examined on purity by preliminary X-ray fluorescent analysis and by neutron activation method. All the samples are of natural isotopic composition. Neutrons were generated by the T(d,n)^{4}He nuclear reaction. Low-voltage accelerator of charged particles was used. Mixed beam of ions D^+ and D_2^+ was accelerated by 220 kV potential. The diameter of deuteron beam on the T-Ti target was 25 mm. But the concentration of tritium at the central part of the target was approximately zero. This fact was confirmed by comparing of calculated at the assumption of uniform concentration and measured average energy of neutrons. Another confirmation of this fact is the experimental and calculated neutron flux density at the irradiation points. The distance from the set of samples to T-Ti target was 5.5 mm. The time of the irradiation of samples was chosen 1.33 hour for considered nuclear reactions. The average neutron flux density at the irradiation points was determined by using of niobium samples. The sample of germanium was placed between two foils of niobium with the same diameter at the irradiation time. The reference nuclear reaction for the flux density measurements was ^{93}Nb(n,2n)^{92m}Nb. The set of samples of niobium and germanium was placed between two samples of zirconium. The samples of zirconium and niobium were used for the determination of the average energy of neutrons at the irradiation points by Zr/Nb method [4, 5] The set of samples of niobium, zirconium and germanium at the time of irradiation were covered by 0.4 mm cadmium foils to reduce the influence of thermal neutrons. Diameter of germanium, niobium and zirconium

samples was 10 mm or 20 mm. Thicknesses of germanium, niobium and zirconium samples are 0.7 mm, 0.1 mm, 0.03 mm accordingly for 10 mm diameter and 3 mm, 0.1 mm, 0.3 mm accordingly for 20 mm diameter.

The spectra of activation products were measured by γ-spectrometer with HPGe-detector (sensitive volume $\sim$110 cm^3) and by X-ray spectrometer with planar Si(Li)-detector (active area $\sim$28 mm^2, thickness $\sim$2.5 mm). The distance from the sample to the sensitive area of the X-ray detector was 15 mm with 4 mm diameter collimator. The self-absorption correction was calculated by Monte-Carlo simulation method with taking into account the non-uniform distribution of activity and the influence of detector edge effects [5, 6]. X-rays spectra of germanium samples should be measured after 21 days from the irradiation time. This cool-down time is necessary for ^{72}Ge(n,2n)^{71}Ge nuclear reaction cross section measurement. After this period of time one can neglect the activity of all other activation products of germanium isotopes. The activity of X-rays after this period of time will be formed only by electron capture decay of ^{71}Ge. Measurements of γ-spectra were carried out at 81 mm distance to the sensitive volume of HPGe-detector because of high activity of the irradiated samples. The correction on true coincidence summing of gamma-quanta and on finite geometry effects are applied [5]. True coincidence summing correction is calculated by semi-empirical method [5]. Besides the γ-γ true coincidence the influence of X-rays originating from internal conversion or preceded by electron capture, positron annihilation photons, absorbed and scattered in the sample γ-radiation, bremsstrahlung radiation are considered. The calculation of the correction on the dead-time of the spectrometer was performed for the nonstationary conditions of measurements; to do this the spectrometer indication of dead-time losses with the a posteriori separated contributions to the total activity was used. The calculation of primary neutron source spectra profile was performed with computer code SPECTRON (Khlopin Radium Institute, St.Petersburg, Russia). The full width at half maximum of neutron spectrum was derived from these calculations. The geometry of irradiation and the most considerable parameters of the neutron generator set and of the neutron generator hall were taken into account at the calculations of the secondary neutrons spectra profile by Monte-Carlo method.

III. EXPERIMENTAL RESULTS

Average neutron energy determined by Zr/Nb method was (13.96±0.06) MeV. The calculated full width at half maximum (FWHM) of the primary neutrons spectrum profile was 0.4 MeV. The energy resolution in this case was 0.2 MeV=(FWHM)/2. The average neutron flux density at the irradiation point was $\sim 3.6 \cdot 10^8$ $cm^{-2} \cdot s^{-1}$. Calculated with evaluated data from JEF-2.2 library correction on the secondary neutrons for $^{76}Ge(n,\gamma)^{77(g+0.21m)}Ge$ nuclear reaction was ∼0.8. One can conclude based on this value that the main contribution to the measured activity of ^{77}Ge is from primary neutrons. Evaluated by author [5] cross section of reference nuclear reaction $^{93}Nb(n,2n)^{92m}Nb$ (456±6) mb was used. All decay data were taken from [7]. Results of the experiment are summarized in the Table I. The results of other authors were taken from [3]. All of our results are in good agreement with recent experimental results of other authors. There is no information on experimental measurements of $^{72}Ge(n,2n)^{71}Ge$ and $^{76}Ge(n,\gamma)$ nuclear reaction cross sections at the considered neutron energy range. This fact gives us the opportunity to note that these values were measured at first. Our results for these two nuclear reactions are in good agreement with evaluated data from most of evaluated libraries. The cross sections of (n,2n) and (n,γ) nuclear reactions on other naturally occurring isotopes of germanium could not be determined by activation method.

TABLE I: The comparison of our data with the the data of other authors (in mb)

Reaction	$T_{1/2}$	This work	Other works [1)]
$^{70}Ge(n,2n)^{69}Ge$	39.05 h	420±30	407±49 (13.99, Konno, 1993) 392±61 (13.9, Hoang, 1992)
$^{72}Ge(n,2n)^{71}Ge$	11.43 d	780±60	no results
$^{76}Ge(n,\gamma)^{77(g+0.21m)}Ge$	11.30 h	1.01±0.14	no results
$^{76}Ge(n,2n)^{75}Ge$	82.78 m	1310±140	1300±101, (14.10, Molla, 1997) 1160±130 (14.00, Steiner, 1969)

[1)] The neutron energy, first author and year of publication are given in parenthesis

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